Characteristic X-rays from silver foils for backlighting of WDM

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The goal of experiments carried out at GSI with high intensity laser system PHELIX is the investigation of mechanisms leading to effective production of photons with energies above 20 keV required for monochromatic backlighting of Warm Dense Matter (WDM). In experiments, 1ω, 500fs, 100J laser pulses were used for irradiation of 3 mm thick Ag targets and thin foils deposited on Al and plastic substrates. The laser intensity was varied between 10^{18} and 4×10^{19} W/cm^2 by changing the laser focal spot size. In this report we present a comparison of numerical simulations of the silver K_α-photon yield with experimental results obtained by means of a single-hit CCD technique [1].

In simulations, the K_α-photon yields from Ag foils in given direction into a unit of solid angle per laser pulse energy, $N_{\rm k}$, were calculated according to the model [2], which takes into account dependencies of the conversion efficiency of laser energy into hot electrons $\eta(I_{\rm L})$ [1] and average energy of hot electrons $T_{\rm h}(I_{\rm L})$ [3] on the laser pulse intensity $I_{\rm L}(r,t)$, as well as a self-absorption of 22.1 keV K_α photons in a foil of arbitrary thickness. In the case of Gaussian laser pulse, $I_{\rm L}(\upsilon) = I_0 \exp(-\upsilon)$, $\upsilon = r^2/r_0^2 + t^2/t_0^2$, we get

$$\begin{aligned} N_{\rm k} &= \frac{2}{\sqrt{\pi}} \int_0^\infty \sqrt{\upsilon}\, {\rm d}\upsilon \frac{\eta(\upsilon)\, e^{-\upsilon}}{T_{\rm h}^2(\upsilon)} \times \\ &\times \int_{E_{\rm k}}^\infty {\rm d}E_0 \exp\left[-\frac{E_0}{T_{\rm h}(\upsilon)}\right] \frac{{\rm d}N_{\rm em}(E_0)}{{\rm d}\Omega}\,, \end{aligned}$$

were ${\rm d}N_{\rm em}(E_0)/{\rm d}\Omega$ is the number of photons per steradian, emitted by an electron, normally incident with initial energy E_0, from the front side of the foil in given direction.

Theoretical dependencies $N_{\rm k}(I_0)$, calculated with the assumption of suppression of hot electron refluxing, describe well features revealed in experiments: sharp increase of K_α-photon yield in the intensity range (1.5–2)$\times 10^{18}$ W cm^{-2}, and then relatively small decrease of $N_{\rm k}$ with growth of the intensity up to 3.4$\times 10^{19}$ W cm^{-2} (Fig. 1(a)). The K_α-photon yield increases up to 3 times with increase of foil thickness from 10 to 100 μm (cf. Figs. 1(a) and (b)). The last two features confirm the assumption about suppression of hot electron refluxing in foils deposited on the bulk substrates, even at high laser intensities. The K_α yield from the foil of 10 μm thickness with refluxing electrons, calculated for intensity $I_0 \approx 2.5 \times 10^{19}$ W cm^{-2} [2], exceeds shown in Fig. 1(a) value for the foil with single-pass electrons about 44 times, so only very small input from refluxing electrons could cause insignificant deviations of the experimental value from calculated one (see Fig. 1(a)).

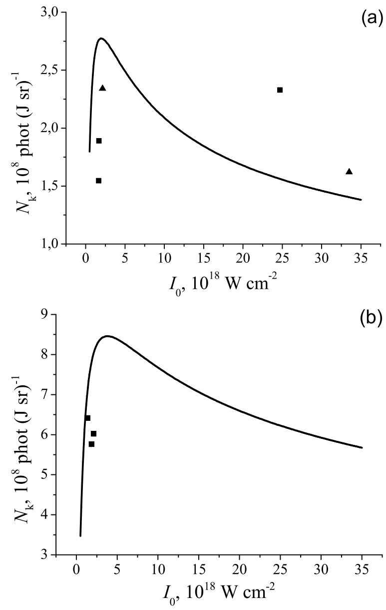

Figure 1: The K_α photon yield vs laser pulse intensity. Solid lines correspond to calculated values with Ag foils of thicknesses: (a) 10 μm and (b) 100 μm. Points correspond to measured values, multiplied by a factor 3: (a) Ag foil of 10 μm thickness deposited on bulk plexiglass (squares) and bulk Al (triangles); (b) Ag foil of 100 μm thickness deposited on bulk plexiglass.

It is important to point out that strong suppression of hot electron refluxing takes place as well for non-conductive substrates like a plexiglass. The last allows supposing the presence of plasma channels in dielectric substrates which occur due to ionization caused by the self-consistent electric field of the electron bunch [4]. Systematic overestimation by a factor about 3 of calculated K_α-photon yields over measured absolute values will be a subject of future analysis (see also [5]).

References

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